Studies of Avalanche Photodiode Performance in a High Magnetic Field

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Abstract

We report the results of exposing a Hamamatsu avalanche photodiode (APD) to a 7.9 Tesla magnetic field. The effect of the magnetic field on the gain of the APD is shown and discussed. We find APD gain to be unaffected in the presence of such a magnetic field.

Key words: Avalanche photodiode; Magnetic field

1 Introduction

The avalanche photodiode (APD) is a solid state photodiode with internal gain. It has been chosen as the baseline photodetector for the electromagnetic crystal calorimeter (ECAL) of the Compact Muon Solenoid (CMS) Detector at the Large Hadron Collider at CERN in Geneva, Switzerland. [1] The ECAL consists of some 60,000 lead tungstate ($PbWO_4$) crystals, each to be read out by a pair of APD's. Among the reasons for choosing the APD are high quantum efficiency, a weak response to minimum ionizing particles, otherwise known as the nuclear counter effect, and, as we show here, an insensitivity to high magnetic fields. At the CMS experiment, the magnetic field provided by the superconducting solenoid will be 4 T. Here we present the results of tests carried out to investigate the performance of a Hamamatsu APD, similar to the one chosen for CMS, in the presence of a 7.9 T field. While it has been widely believed that such a magnetic field would have little or no effect on

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Table 1
Basic parameters of Hamamatsu APD

Active area	5×5 mm^2
Effective thickness (@M = 50)	5.5 μm
Capacitance	125 pF
Quantum efficiency (for $\lambda = 480$ nm)	76%
Excess noise factor (@M = 50)	2.1
Temperature coefficient of gain (@M = 50)	2.3%/°C

APD's, this is, as far as we know, the first explicit measurement of APD performance in a strong magnetic field with modern devices.

2 APD Studied

The APD studied was an experimental model developed by Hamamatsu for CMS. The gain (M) of the APD, determined at bias voltage V_b, was calculated using Eq. 1. I_d, I_{ill}, and I_{ph} are the dark current, the illuminated current, and the photocurrent, respectively. The photocurrent is the difference between the illuminated and dark current. Illumination was provided by the light-emitting diode (LED) described in Section 4.

$$M(V_b) = \frac{I_{ill}(V_b) - I_d(V_b)}{I_{ill}(30V) - I_d(30V)} = \frac{I_{ph}(V_b)}{I_{ph}(30V)} \quad (1)$$

The photocurrent at 30 V was used to determine the gain because in this region of bias voltage, the photocurrent is essentially constant and the gain is assumed to be equal to one. The working bias voltage for a gain of 50 is approximately 355 V at a temperature of 25 degrees C [2]. Other parameters describing the APD are found in Table 1 [2].

3 The Magnetic Field

The 7.9 T field was produced by a solenoidal magnet in the High-Field EPR Laboratory at Northeastern University. The magnet, produced by NMR Magnex Scientific Inc., features a horizontal room-temperature bore design that allows convenient optical access to the region of highest field homogeneity. The accessible region of the magnet is a cylindrical volume of diameter 60.5

mm and length 0.650 m. The field possesses homogeneity typical of magnets used in NMR applications, with a maximum inhomogeneity of 0.2 ppm. The region of maximum homogeneity is a cylindrical volume in the center of 1 cm in diameter and 1 cm in length. Measurements were performed with the APD in this cylindrical volume.

4 APD Test

4.1 Experimental Set-Up and Procedure

The APD was mounted inside a light-tight container and was connected to a blue light-emitting diode (LED) with optical fiber. The blue LED was a model NSPB320BS produced by Nichia America Corporation and emits light at a peak wavelength of 460 nm. The set-up allowed for the surface of the APD to be oriented parallel and perpendicular to the direction of the magnetic field. At each of these orientations, the APD was inserted into the center of the solenoid and the dark current (I_d) and the illuminated current (I_{ill}) were measured as the bias voltage (V_b) was increased from 30 to 360 volts. From these values, the gain (M) as a function of V_b was obtained using Eq. 1. For comparison, this procedure was also repeated with the APD outside of the field. The bias source voltage was provided by a Keithley 2410 Sourcemeter; the current measurements were performed with this device as well.

4.2 Analysis and Results

The gain values for each value of the bias voltage for the runs conducted outside of the field (five runs total) were averaged and appear in Fig. 1. For each run conducted inside the field (one at each orientation), and for each value of the bias voltage, the gain was divided by the average value of the gain from the runs conducted outside of the field. These values appear in Figs. 2-3. The plots indicate that there appears to be no effect on the performance of the APD in the presence of the magnetic field.

5 Summary

An experimental avalanche photodiode (APD) produced by Hamamatsu was exposed to a 7.9 T magnetic field. The surface of the APD was oriented both parallel and perpendicular to the field. At each orientation, the dark current

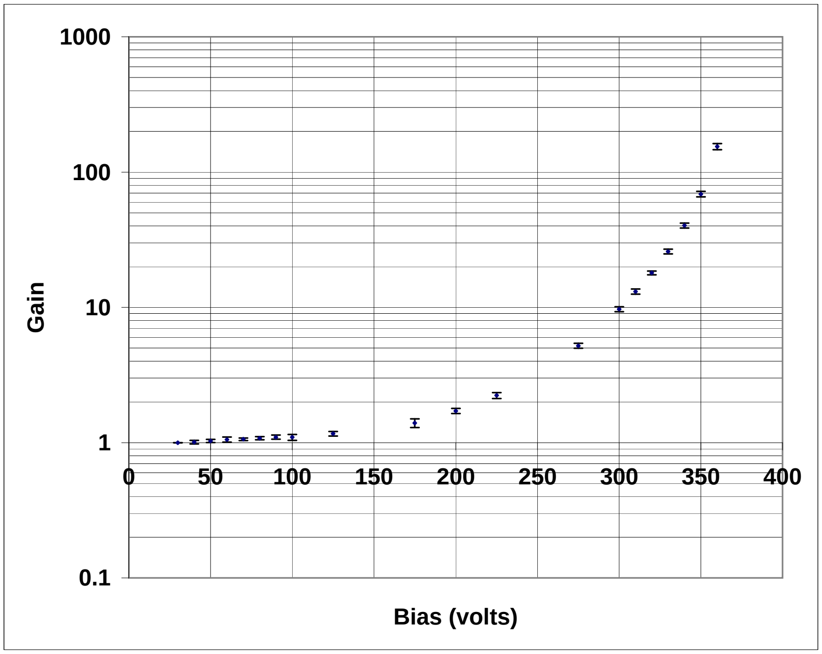

Fig. 1. Average gain of runs conducted outside the field vs. bias voltage.

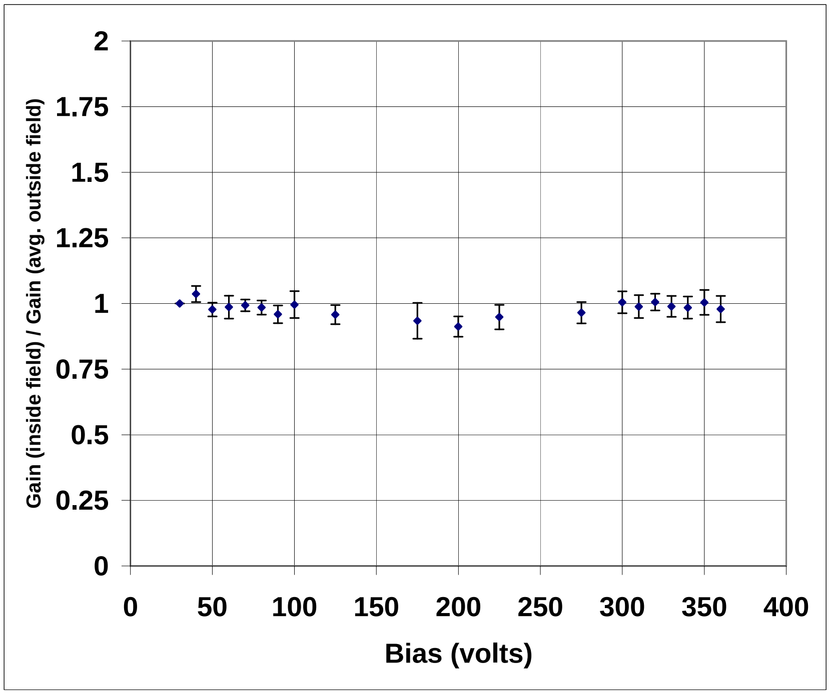

Fig. 2. Comparison of gain with surface of APD oriented perpendicular to the field with average gain of runs conducted outside the field.

(I_d) and illuminated current (I_{ill}) were measured as the bias voltage (V_b) was increased from 30 to 360 volts. From these values the photocurrent (I_{ph}) and gain for each value of the bias voltage were obtained. For comparison, this procedure was also performed with the APD outside of the magnetic field.

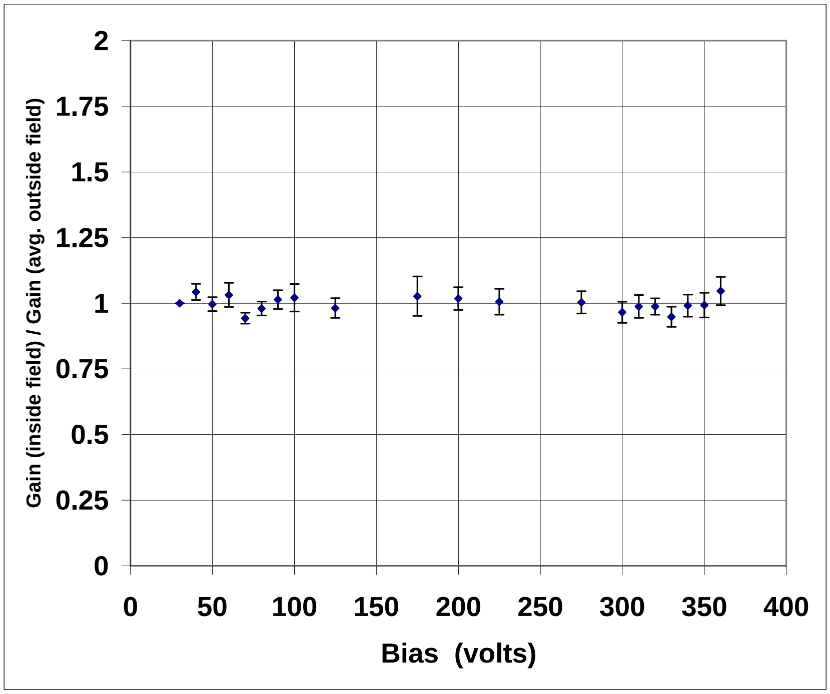

Fig. 3. Comparison of gain with surface of APD oriented parallel to the field with average gain of runs conducted outside the field.

From this comparison, we find that APD gain is unaffected by the presence of a 7.9 T magnetic field.

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References

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